

## Using Arbitrary/Function Generators to Simulate Polyphase Power Line Waveforms

### Introduction

Polyphase signal generation is required for a broad range of test applications. For example, the power industry uses three-phase signals to assess the performance of equipment used in condition monitoring or fault detection systems. These tests require the simulation of three-phase sine waves with line frequencies, ranging from 50 - 800 Hz, where fault conditions or high frequency noise are introduced.

Three-phase AC power supplies may be considered for these polyphase applications. However, they are restricted by bandwidth limitations, the lack of independently controlled phases, high cost and the inability to recreate real-world waveforms as in reconstruction of fault conditions.

Alternatively, arbitrary/function generators may be used. Their arbitrary waveform capability allows the digital reconstruction of virtually any wave type at frequencies much higher than programmable power supplies. This makes it possible to recreate high frequency fault conditions such as arcing, noise or voltage surges. Arbitrary/function generators cost much less than programmable power supplies and appear to be the clear choice for these applications. However, not all arbitrary/function generators are created the same. Some arbitrary/function generators lose phase accuracy when the frequency is adjusted. Others lack the resolution (waveform memory or clock speed) needed to accurately recreate a real-world signal.

TEGAM's 2700 series arbitrary/function generators address the synchronization, phase shift and resolution issues. Up to twenty channels of output may be accurately synchronized with the highest precision. The output frequency may be adjusted independently or dependently without the need to recalibrate phase offsets. TEGAM's 2700 series arbitrary/function generators offer up to 4 M of waveform memory and 50 MHz of bandwidth.

The 2700 series arbitrary /function generators are ideal for simulating pulse, noise, sensor stimuli, speed profiles or faults. Unique events such as partial discharge, phase imbalance, drop outs, arcing or lightning surges may be digitally edited and downloaded into the 2700's extended memory. Waveforms are created by using wave editing software, the unit's front panel, or direct import from an oscilloscope. The outputs of the units are sufficient to

drive high impedance loads such as inputs to data acquisition or other sensing devices. TEGAM offers a line of voltage or current amplifiers for applications where additional voltage or current is required.

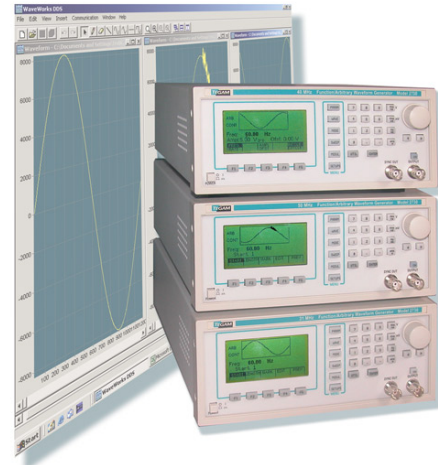


Figure 1 – TEGAM offers single or dual channel versions of arbitrary/function generators. Multiple generators may be synchronized to create up to 20 phase-calibrated outputs.

### Scope

Our scope is to demonstrate the hardware and software configurations for creating a three-phase arbitrary signal using three TEGAM 2730 arbitrary/function generators. WaveWorks DDS, wave-editing software will be used to create sine waves for each of the phases. Noise will be superimposed onto one of the phases simulating a fault condition. The units are synchronized to each other using their programmable marker outputs. This configuration is not limited to three-phase sine waves. It extends to any application, which requires single to polyphase (up to 20 channels) generation of low/high frequency arbitrary waveforms.

### Tools & Equipment

- 3- TEGAM Model 2730, 125 MS/s arbitrary/function waveform generators (2725, 2730 or 2732 may be used)
- 1- WaveWorks DDS Wave Creation Software (included accessory)
- 1- P/N BNC-3285, BNC Tee Connector
- 7- P/N CBL-3102, 3 ft BNC Cables
- 3- P/N 1583-3, 3 ft GPIB cable (6 & 9 ft cables available)
- 1- PC with GPIB capability (RS232 optional)
- 1- Multi-channel Oscilloscope
- 3- P/N 1000001, RS232 to USB Converter (Optional)

### Instrument Setup and Initialization

Three Model 2730, 125 MS/s arbitrary/function generators will be synchronized to simulate the polyphase sine waves. Designate each unit as being phase A, B, or C. Power each unit and press [SETUPS] > [F1-RECALL] > [0] > [ENTER]. This will return each of the units to its factory default settings. Next, verify that the memory protection feature is disabled so that new wave data may be written into memory. Press [WAVE] > [F5-ARB] > [F4-EDIT] > [F4-MORE] > [F3-PROT]. Verify that [F3: ALL] is highlighted. Make sure that [F4] is in the “OFF” condition. Repeat these steps for each unit.

The TEGAM 2730 arbitrary/function generators have the capability to share a master clock between multiple units. Unit A will be configured as the master clock for units, B and C. In unit A, press the [PARAM] key and verify that [F5], the reference soft key is set to internal. This is verified by “INTCLK” being highlighted. Repeat these steps on the B and C units making sure that their reference inputs are set to “EXTCLK” and that the [F1: FREQ/RATE] is set to “RATE”. Units B and C will be designated as the slave units.

### Setting the Trigger Modes

The 2730 may be run in continuous, triggered, gated or burst modes. The master unit or phase A unit will be run in continuous mode. Press the [MODE] key and select [F1-CONT]. Set Phases B and C to operate as slave units by pressing [MODE] > [F2: TRIG] > [F3: EXT]. External triggering causes the instrument to wait for an external signal at its TTL, trigger input. Because phase A is set to continuous trigger mode and phases B and C are set to external trigger, they will follow phase A with jitter free operation.

### Setting the GPIB Addresses

The GPIB interfaces will be used to transfer the wave data from WaveWorks DDS to each of the instruments. Each instrument must be assigned a unique GPIB address. Press [UTIL] and make sure that “GPIB ACTIVE” is shown above the [F1] key. If it is not then press [F1] until “ACTIVE” appears. Adjust the dial or use the numerical keypad to enter a unique GPIB address for each of the phases and then press [ENTER] to store the new address. Repeat this process for each of the units. Note the addresses and their respective phases for future reference.

### Wiring and Configuration

Unit A provides the master sample clock signal (REF OUT) to units B and C (REF IN). This configuration allows units A, B and C to share the same sample clock. Because A is the master, the sample rates of B and C will follow A. Refer to Figure 2 and connect the BNC cables for the clock references as shown.

The fully programmable marker outputs are used to trigger the subsequent channel at a 120° phase shift. The position of the marker defines the phase offsets between A, B and C. The starting address and width of each marker output can be defined at any location within the instruments 4 mega points of waveform memory. Refer to Figure 1 and connect the BNC cables for the “MARKER OUT” and “TRIG IN” connections as shown.

GPIB will be used as the primary communications interface. Connect the GPIB cable from the PC to the GPIB connector in the rear panel of the phase A, 2730 unit. Piggyback the GPIB cables for B and C onto the A connector. Connect the oscilloscope to the bus if wave data will be uploaded into WaveWorks DDS. Use Figure 2 as a reference for these connections.

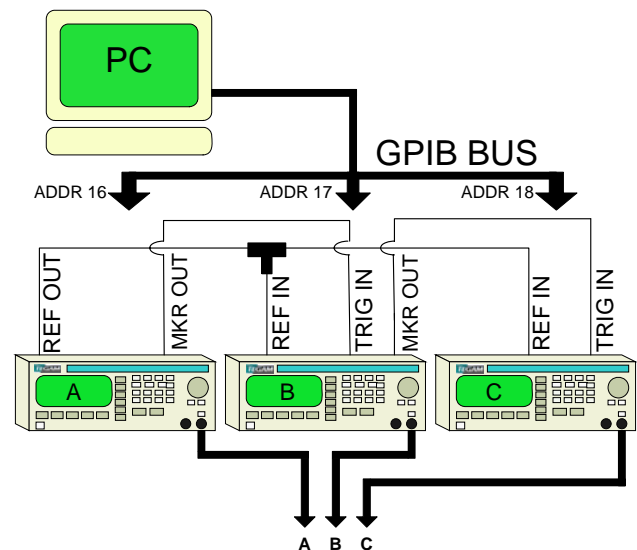


Figure 2 –Connection diagram for GPIB-driven polyphase operation. The 2700 series provides standard RS232 and GPIB interfaces. An optional RS232-to-USB converter is also available.

### Loading and Sending the Wave Data

WaveWorks DDS allows the simulation of partial discharge, phase imbalance, drop outs, arcing or lightning surges as used in testing fault detection equipment or other applications. This is achieved by enabling the user to create, edit, import or export wave data to TEGAM 2700 arbitrary/function generators via RS-232 or GPIB interfaces. WaveWorks DDS is compatible with \*.txt files, which may be imported from Excel, Matlab, Notepad or other versions of WaveWorks software. It also offers the direct import of wave data from popular Agilent and Tektronix oscilloscopes.

Two sine waves will be created using WaveWorks DDS, one clean and the other with a noise spur. The clean sine wave shall be downloaded to phases A and C. The sine wave with the noise will be downloaded to phase B.

Install and run WaveWorks DDS. Select Insert > Sine and a dialog box will appear. Set the starting point to 1, length to 1200, scale to 1.00 and the offset to 0.00 and press OK. A 1200-point sine wave should appear on your screen.

Send the clean sine wave to phase A (GPIB addresses 16). By pressing File > Instruments > Model 2730. Next, select Communication > Send Waveform > GPIB. A pop-up window will appear allowing you to define the start point, data length and instrument address to send the wave data. Enter the required parameters into the dialog box. Refer to Table 1 for settings. Press “Send” and the data will download to the designated instrument. Repeat for phase C (address 18).

*NOTE: Waveforms will not appear at outputs B and C until the programmable markers on units A and B have been enabled.*

Instrument Settings	Phase A Master Unit	Phase B Slave	Phase C Slave
GPIB Address	16	17	18
Wave Data	Sine Wave	Sine Wave with noise	Sine Wave
Marker Location	400	400	0
Data length	1200	1200	1200
Starting Address	1	1	1
Reference Clock	Internal	External	External
Trigger Mode	Continuous	External	External

Table 1 – Instrument settings for polyphase operation.

Next we will add a noise spur to the sine wave for phase B. Select Insert > Noise and a dialog box will appear. Set the starting point to 400, length to 50, scale to .20 and the offset to 0.00. Select “Add To Existing Waveform” then press OK. A 100-point noise spur will be superimposed between 90 and 180 degrees of the sine wave. Send this waveform to phase B (address 17).

### Using the Markers to Offset the Phases

For this three-phase simulation, there must be a 120° offset between each of the channels. This can be done by either manually editing the waveforms or setting the location of the markers and triggering each channel.

The marker’s address location, Y, is dependent upon the number of samples, N<sub>s</sub> within a complete cycle of the waveform. The marker location, Y is determined for offsets less than 360° by the following formula:

$$Y = \text{int} \left( \frac{N_s \times \text{Phase Offset}}{360^\circ} \right)$$

For wave data where one cycle contains 1,200 data points, the marker locations will be at address 400 for phase A and phase B. This will produce a 120° offset for each channel. Sometimes the division does not produce an exact integer value. In this case, the location of the marker must be rounded creating a slight phase error. This error can be avoided by creating a numerator that is exactly divisible by 360°.

To program the markers so that each channel will be offset by exactly 120° we start with unit A. Press [WAVE] > [F5-ARB] > [MARK] > [F2-ADDR] > [4][0][0] > [ENTER]. Then enable the marker by pressing [F4-ON/OFF] until the “ON” condition is highlighted. This will produce a marker at phase A’s output to trigger phase B at 120°. Repeat this procedure for phase B to trigger phase C. There is no marker output required for phase C.

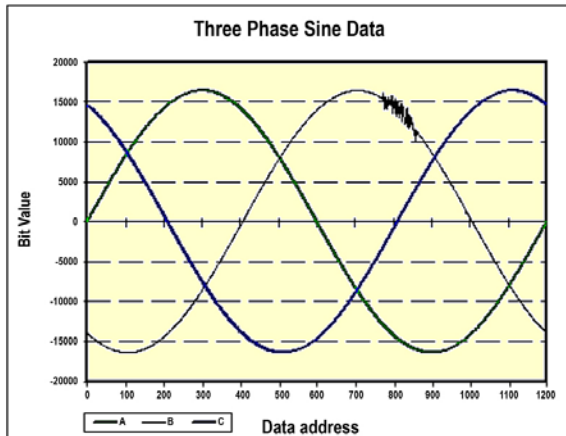


Figure 3 – Three phase sine wave data plotted in an Excel spreadsheet.

### Enabling and Verifying the Outputs

Enable each of the arbitrary/function generator outputs by pressing the OUTPUT [ON] key until an “Out ON” message appears in the upper right hand corner of each LCD. Make sure the oscilloscope is set to a 50  $\Omega$  input impedance. Connect each channel to its respective phase output. Measure the phase offsets between each channel to confirm proper triggering and marker positions. Change the sample clock of the master unit. Phases B and C should follow. You should now have a three-phase, variable-frequency, sine wave (arbitrary signal) source.

To set the output frequency, the clock rate of the master unit A needs to be determined by using the following formula:


$$\text{Clock Rate (S/s)} = F_{\text{out}} (\text{Hz}) \times N_s$$

Where Clock Rate is the sample clock setting in samples per second,  $F_{\text{out}}$  is the desired frequency in Hertz, and  $N_s$  is the number of samples used for each waveform cycle. Because the slave units are configured to follow the master clock only phase A needs to be changed to adjust the output frequency. In this example, we have 1,200 data points for each complete cycle of sine wave. If the desired frequency is 400 HZ then the required sample rate is 400 X 1,200 or 480 S/s. Making sure that each unit is in the arbitrary waveform mode, set the master A clock to this value by pressing [PARAM] > [F1: FREQ] > [4][8][0] > [KHz] and confirm the change in output frequency for channels A, B, and C.

### Determining the Final Amplitude

The output amplitude is determined by the product of the DAC output times the amplitude setting. In WaveWorks DDS, the sine wave scale was set to 1.00, which produces exactly the amplitude setting. The scale of the noise was set to .2, so its p-p value will result in the product of .2 X the amplitude setting.

### Conclusion

Arbitrary/function generators are highly versatile instruments with the capability to replicate just about any type of waveform. A polyphase configuration extends the usability of these generators beyond applications traditionally addressed by three phase power supplies. TEGAM's 2700 series arbitrary/function generators offer higher bandwidth, waveform precision, phase accuracy and flexibility at a lower cost. Contact a TEGAM representative to learn more about how we can resolve your signal generation needs with our high performance test and measurement solutions. 

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### Technical Sales Contact:

Stephen Kosik, Applications Engineer  
TEGAM Inc.  
10 TEGAM Way, Geneva, Ohio 44041  
TEL: 440.466.6100, [www.tegam.com](http://www.tegam.com)